

image pixel's primary color, the partition within which the dither function is situated is determined. FIG 27 gives an example where the input image consists of uniform color  $C_a$  followed by a sharp transition to color  $C_b$ . Input image color  $C_a$  is to be reproduced by the following amounts of primary colors: 25%  $C_1$ , 25%  $C_2$ , 25%  $C_3$  and 25%  $C_4$ . Input image color  $C_b$  is identical to primary color  $C_3$ . One may verify that exactly starting from the point of transition between  $C_a$  and  $C_b$ , the dither function  $G(x)$  is located in partition  $P_3$  and that therefore color  $C_3$  is selected as output primary color.

## CLAIMS

What is claimed is:

1. A multi-color dithering method for the reproduction of color input images, the method being characterized by the use of a two-dimensional dither function, the use of an arbitrary number of primary colors and the use of partitions representing relative amounts of primary colors, the method comprising the steps of:
  - (a) defining a two dimensional dither function  $G(x,y)$ ;
  - (b) choosing a set of primary colors  $\{C_i\}$  located within a three-dimensional color working space ABC;
  - (c) initiating a neighbor finding procedure which renders neighboring primary colors  $\{C_j\}$  of a given input color  $C$  in the three-dimensional color space ABC;
  - (d) computing the primary color of each output image pixel  $O(x,y)$  by a set of substeps comprising:
    - (i) locating in the input color image an input color location  $(x',y')$  associated to the output image pixel  $O(x,y)$  and computing its corresponding color  $C(x',y')$ ;
    - (ii) finding  $N$  neighbor primary colors  $\{C_j\}$  of  $C$  in the ABC color space by using the neighbor finding procedure;
    - (iii) computing the amount  $S_j(x,y)$  of every neighbor primary color  $C_i$ ;
    - (iv) determining the output primary color  $O(x,y)$  at output pixel  $(x,y)$  by locating at each position  $(x,y)$  a partition  $P_j(x,y)$  within which the dither function  $G(x,y)$  is situated, where upper and lower boundaries of partitions  $P_1, P_2, \dots, P_N$  are respectively defined by lower boundary 0 and upper boundary  $S_1(x,y)$ , lower boundary  $S_1(x,y)$  and upper boundary  $S_1(x,y)+S_2(x,y), \dots$ , lower boundary  $S_1(x,y)+S_2(x,y)+\dots+S_{N-1}(x,y)$  and upper boundary  $S_1(x,y)+S_2(x,y)+\dots+S_N(x,y)$ , and by assigning to the output primary color  $O(x,y)$  the neighbor primary color  $C_j$  associated to partition  $P_j(x,y)$ ;
- and
- (e) outputting the multi-color dithered output image on an output device.

2. The method of claim 1, where the dither function is a two-dimensional discrete dither function characterized by two basic translation vectors.
3. The method of claim 2, where the two-dimensional discrete dither function is obtained by discretizing a continuous dither function.
4. The method of claim 2, where the discrete values of the two-dimensional discrete dither function are obtained by incrementing ordinal numbers along a space-filling curve.

5. The method of claim 1, where outputting the multi-color dithered output image consists in printing the multi-color dithered output image.
6. The method of claim 1, where outputting the multi-color dithered output image consists in displaying the multi-color dithered output image on a color display.
7. The method of claim 1, where the chosen set of primary colors  $\{C_i\}$  comprises non-standard inks selected from the set comprising transparent non process color inks, opaque inks, metallic inks, variable color inks and fluorescent inks.
8. The method of claim 7, where the non-standard inks are opaque inks, where the original multi-colored dithered image is prepared at a resolution of  $R$  dots/inch and printed at a resolution  $R_p \geq R$  with a registration accuracy  $u_a \geq 1/(2R)$  inch, thereby offering an effective anti-counterfeiting protection, since counterfeiting with printing devices of registration accuracy  $u_a < 1/R$  inch yields ink overlaps resulting in strong color shifts.
9. The method of claim 1, where the dither function is a large dither array incorporating artistic screen shapes and where the chosen set of primary colors  $\{C_i\}$  comprises at least one fluorescent ink which under illumination with UV light reveals the artistic screen shapes present in the multi-color dithered output image.
10. The method of claim 1, where the dither function is a large dither array incorporating artistic screen shapes and where preparing the image at a high resolution of  $R$  dots/inch and printing it at a resolution  $R_p \geq R$  makes it impossible to reproduce the multi-colored dithered image on a copier with a resolution lower than  $R$  without heavy degradation of the artistic screen shapes.
11. The method of claim 1, where the chosen set of primary colors  $\{C_i\}$  is identical to the chosen set of inks plus the color of the substrate thereby fulfilling the requirement of printers requiring that inks are always printed side by side.
12. The methods of claim 1, where the neighbor finding procedure uses a subdivision of the color working space ABC into a set of tetrahedra  $\{T_k\}$  having as vertices the chosen set of selected primary colors  $\{C_i\}$ , where the neighbor finding procedure comprises the step of applying to the set of tetrahedra an interior membership test, thereby obtaining tetrahedron  $T$  containing input color  $C(x',y')$  and where for every neighbor primary color  $C_j$  the computation of their normalized relative amounts  $S_j(x,y)$  comprises the step of finding ratios between the Euclidian distances from the input color  $C(x',y')$  to faces of the tetrahedron  $T$  and the corresponding Euclidean distances from the same tetrahedron's faces to their opposite vertices.
13. An apparatus for color image reproduction by multi-color dithering comprising:
  - (a) an input color image storage unit operable for storing an input color image made of input color image pixels of color  $C(x',y')$ ;
  - (b) a neighborhood calculation unit operable for computing a subset of primary colors  $\{C_j\}$  neighbors of the given input image color  $C$  and operable for computing for each neighbor color  $C_j$  of the set  $\{C_j\}$  a signal  $S_j(x,y)$  giving the relative normalized amount of  $C_j$  in respect to input image color  $C$ ;
  - (c) a dither function storage unit storing the values of a two-dimensional dither function  $G(x,y)$ ;

- (d) a multi-color dithering unit operable for sweeping through all pixels of the output image  $(x,y)$ , operable for finding the input color  $C(x',y')$  of corresponding input image pixels, operable for launching the neighborhood calculation unit to compute a subset of primary colors  $\{C_j\}$  neighbors of  $C(x',y')$  as well as their respective signals  $\{S_j(x,y)\}$ , operable for determining a partition  $P_j(x,y)$  within which the dither function  $G(x,y)$  stored in the dither function storage unit 160 is situated, thereby selecting the primary color  $C_j(x,y)$  associated to  $P_j(x,y)$  as output color  $O(x,y)$ ;
- (e) an output multi-color image storage unit operable for storing the selected primary colors  $O(x,y)$  generated by the multi-color dithering unit and operable for forwarding the primary colors making up the output multi-color dithered image to an output device;
- (f) an output device operable for converting the output multi-color dithered image into a visible color image.
14. The apparatus of claim 13, where the neighborhood calculation unit is a tetrahedral calculation unit operable for computing and maintaining a subdivision of the color working space into a set of tetrahedra, operable for applying the interior membership test and operable for computing from an input image color  $C$  and from primary colors  $C_1, C_2, C_3, C_4$  forming the vertices of the tetrahedron selected by the interior membership test the signals  $S_1(x,y), S_2(x,y), S_3(x,y), S_4(x,y)$  giving the relative normalized amounts of primary colors  $C_1, C_2, C_3, C_4$ .
15. A computing system for multi-color dithering comprising
- a memory operable for storing an input color image made of input color image pixels  $C(x',y')$ , operable for storing the values of a two-dimensional dither function  $G(x,y)$ , operable for storing the code of a neighborhood calculation software procedure, operable for storing a multi-color dithering software procedure and operable for storing an output multi-color dithered image  $O(x,y)$ ;
  - a central processing unit interacting with said memory and running said neighborhood calculation and multi-color dithering software procedures, operable for computing for each output multi-color image pixel an output primary color  $O(x,y)$  selected from a set of primary colors, operable for storing the output primary color  $O(x,y)$  in memory and operable for forwarding the resulting output multi-color dithered image to an output device;
  - an output device operable for converting the output multi-color image into a visible color image.
16. The computing system of claim 15, where the neighborhood calculation software procedure is a tetrahedral calculation software procedure which computes and maintains a subdivision of the color working space into a set of tetrahedra, applies an interior membership test and computes from an input image color  $C$  and from primary colors  $C_1, C_2, C_3, C_4$  forming the vertices of the tetrahedron selected by the interior membership test the signals  $S_1(x,y), S_2(x,y), S_3(x,y)$  and  $S_4(x,y)$  giving the relative normalized amounts of primary colors  $C_1, C_2, C_3, C_4$ , where the multi-color dithering software procedure sweeps through all pixels  $(x,y)$  of the output image, finds corresponding input image pixel colors  $C(x',y')$ , calls the tetrahedral calculation software procedure to find the tetrahedron  $T$  containing the input image color  $C$  and to compute the signals  $S_1(x,y), S_2(x,y), S_3(x,y)$  and  $S_4(x,y)$  and where said